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Electrostatics in Planetary Exploration

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University of Central Florida – 12 October 2001

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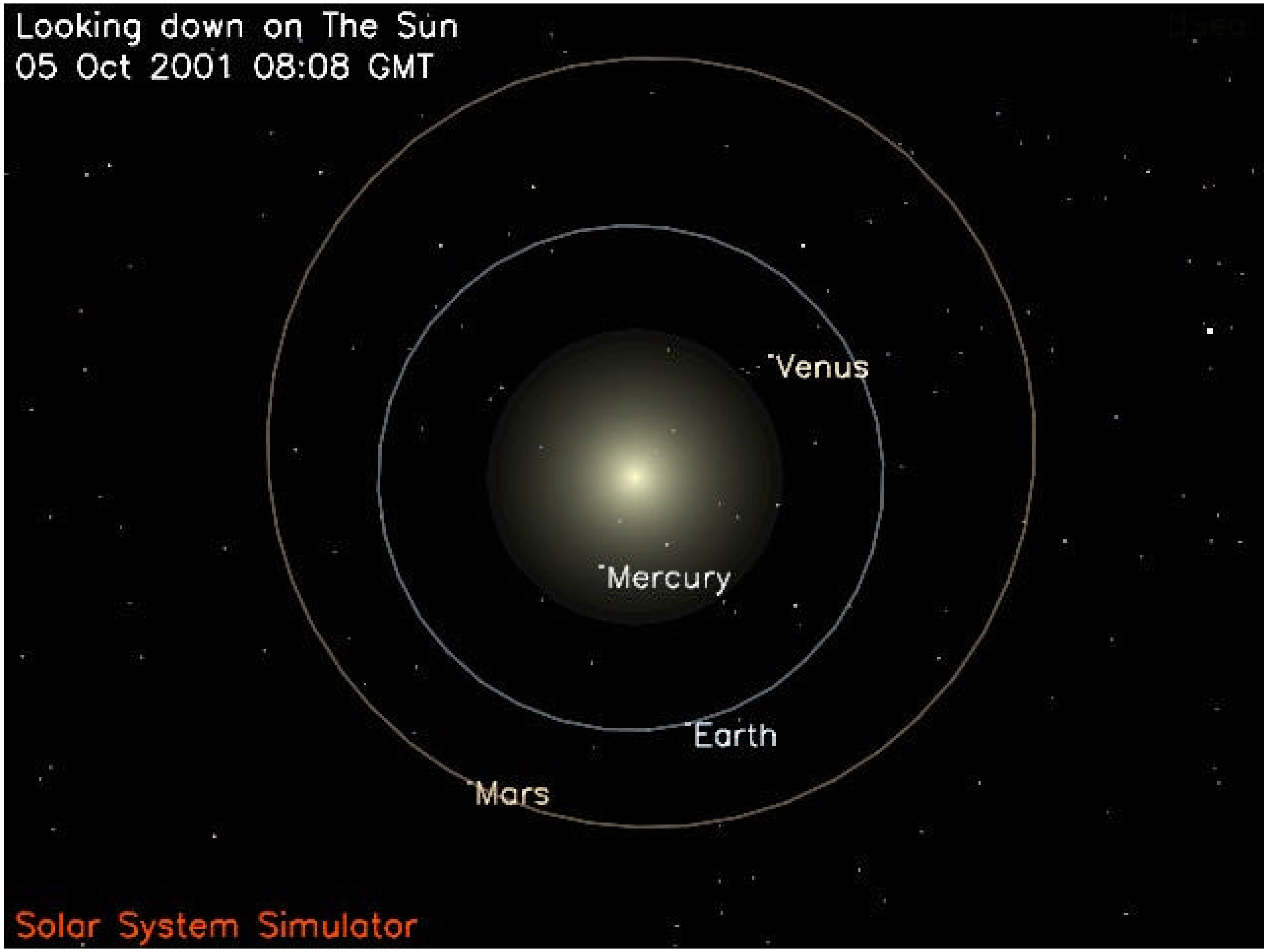
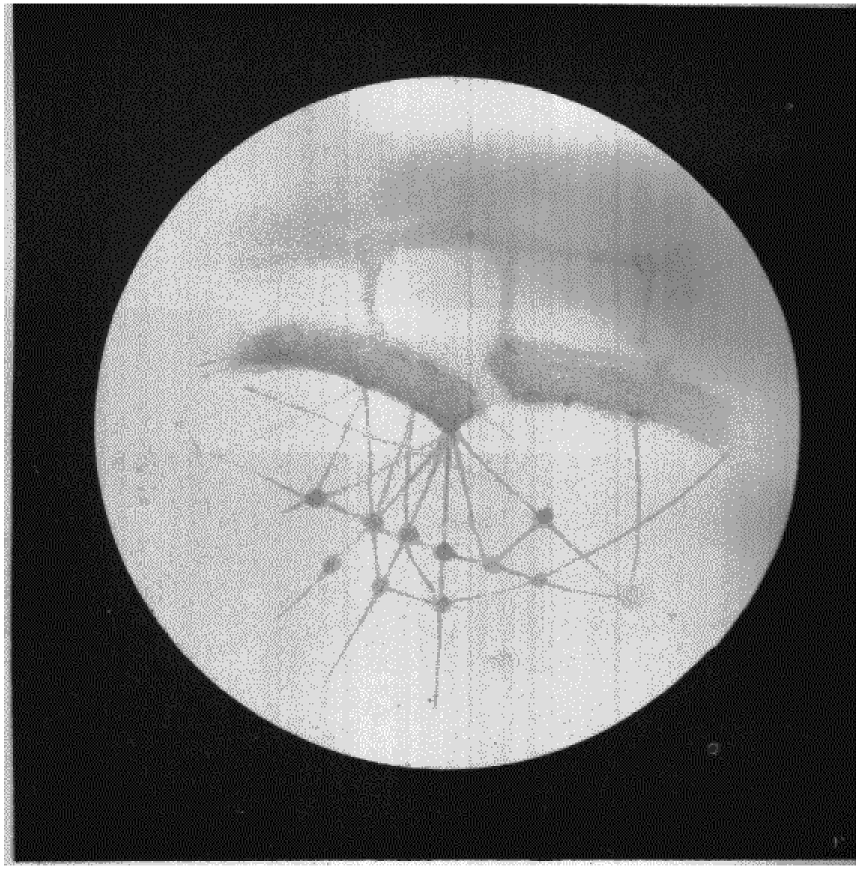
Inner Solar System

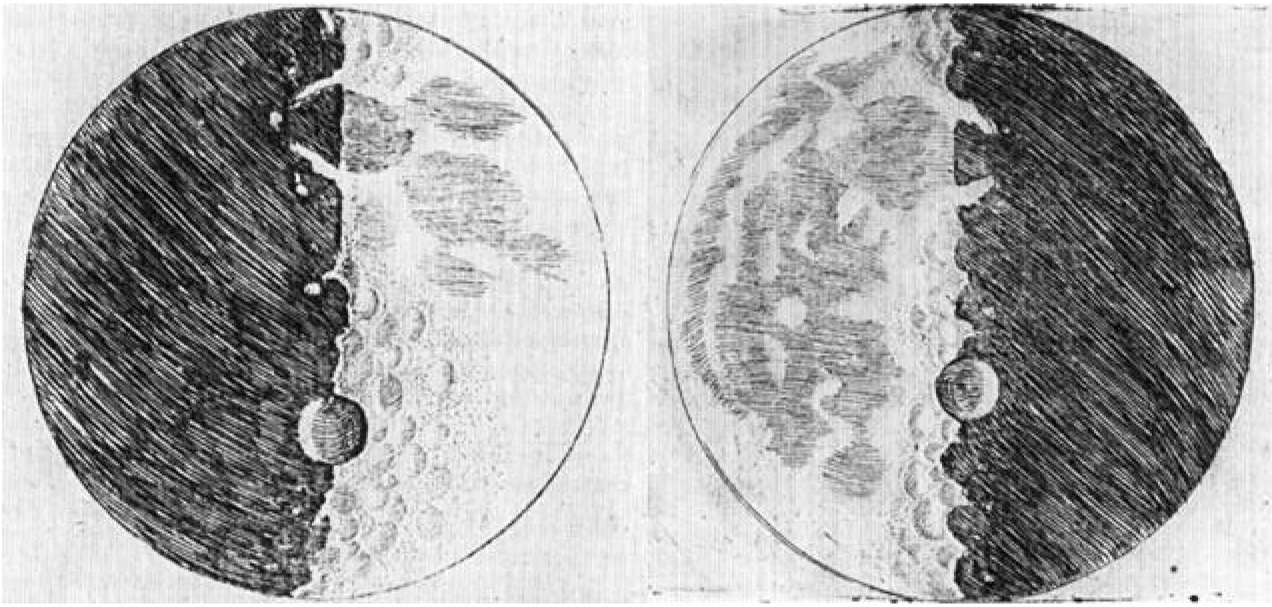


Early Studies of Mars

- Telescopic observations of Mars started with Galileo in 1610
- Giovanni Scaparelli –*canali* (channels)
- Percival Lowell (1895) – “Canals”



Early Lunar Studies



- Galileo's *Sidereus Nuncius* drawings of his first telescopic observations (1610)

Galileo's Moon Wash Sketches

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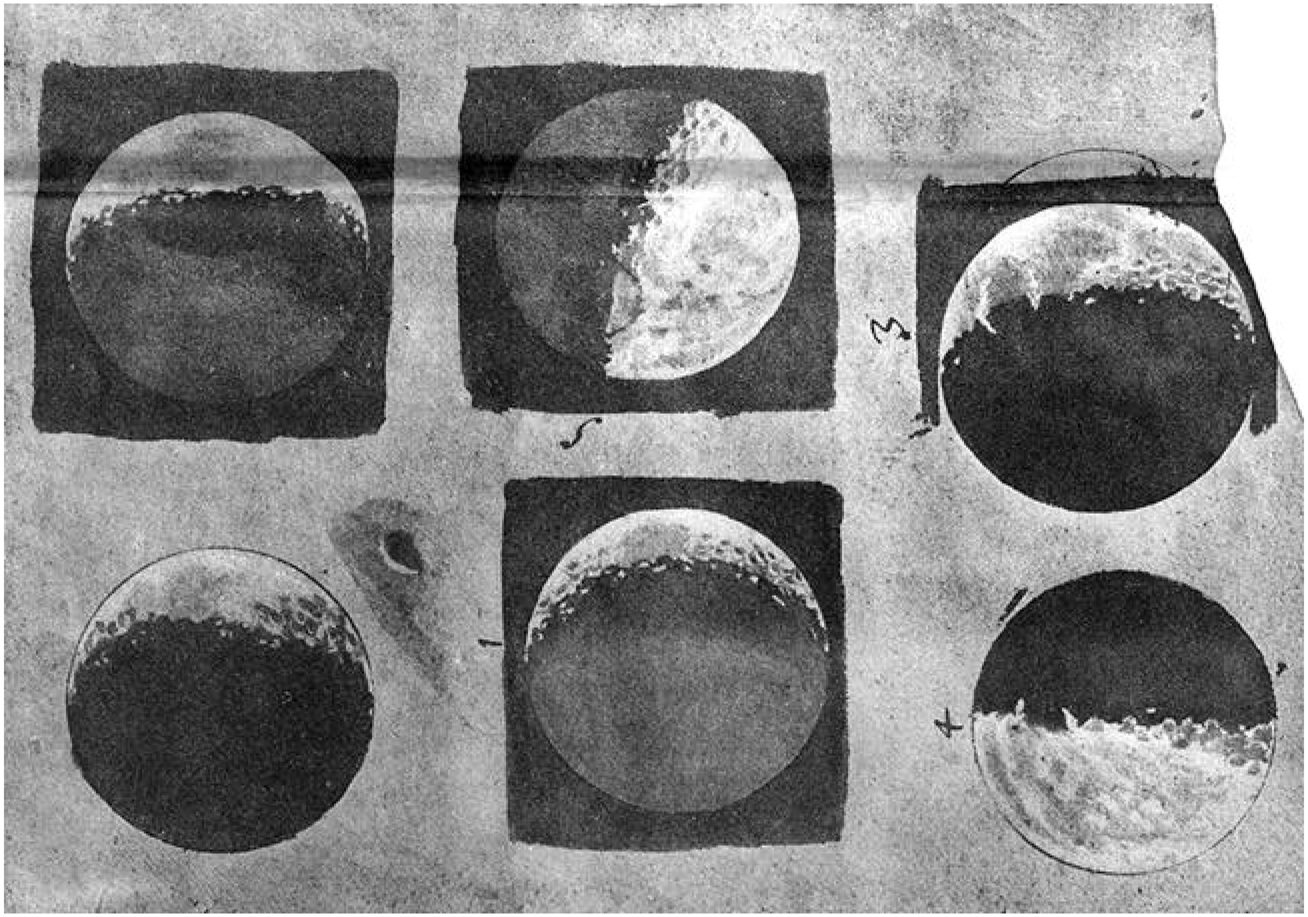

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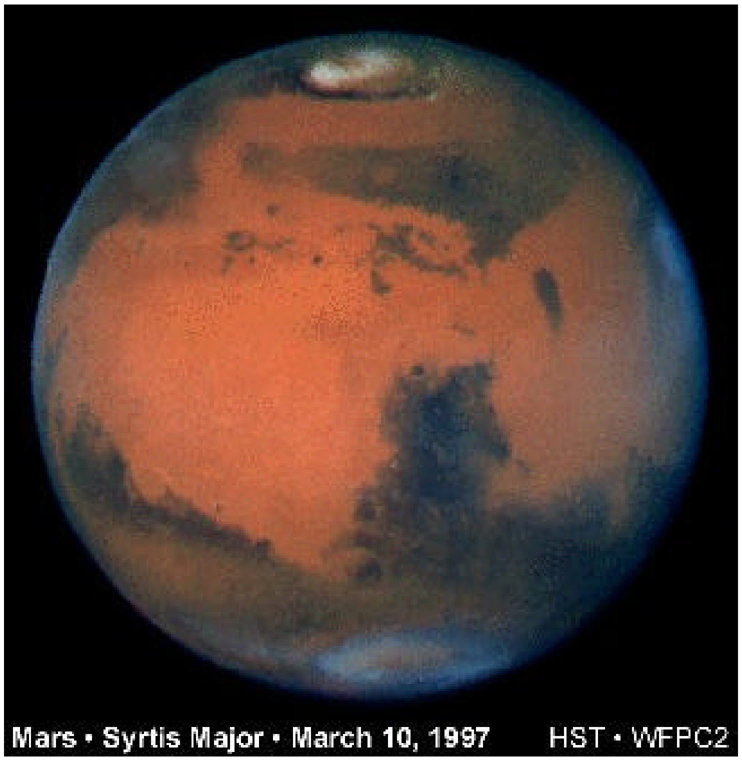
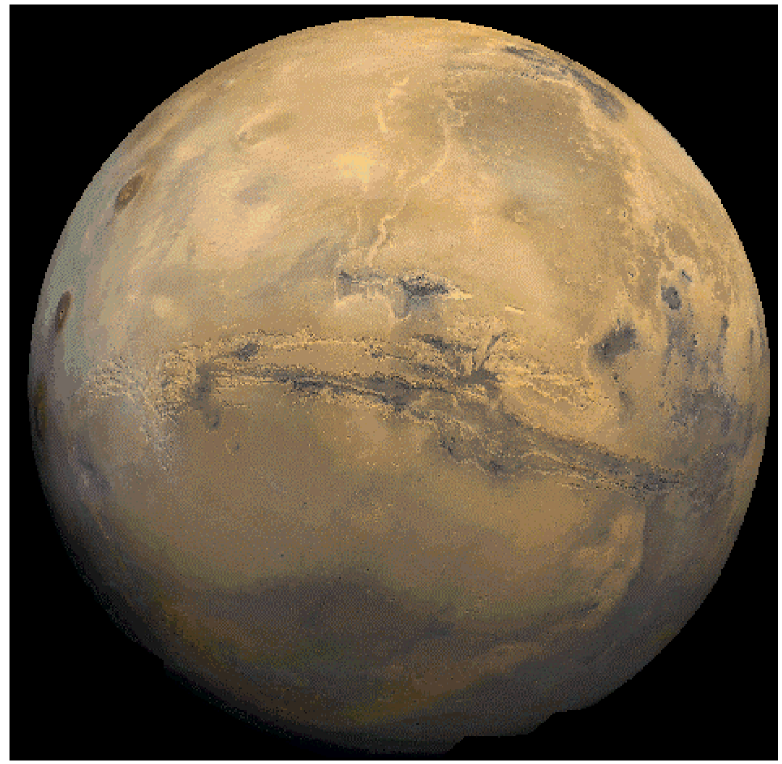
Modern Mars



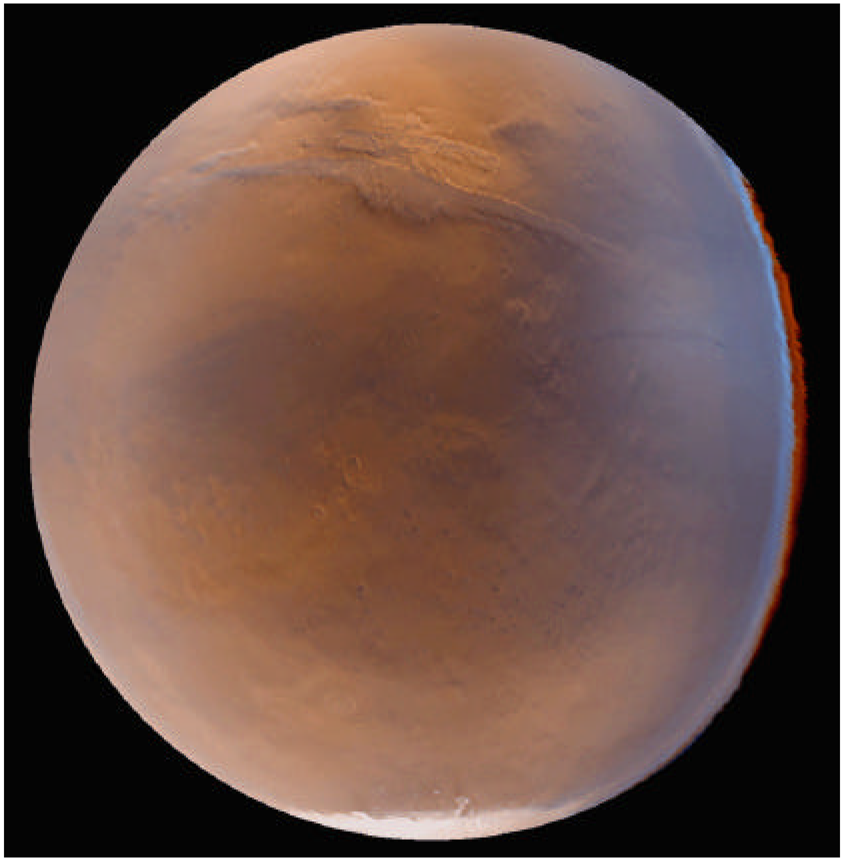
NASA's Space Telescope Photograph (1997)



Viking Mission Photograph (1976)

Mars from MGS Orbit

- View of Mars created from imaging data corrected for distortions and spacecraft motion.
- The image gives an approximation of what Mars would look like through a wide angle lens at an altitude of 2700 km over 30 S, 70 W.
- At the top (north) of the image is Valles Marineris, the system of canyons which stretches for over 4000 km.
- The white area at the bottom of the image is the south polar cap. The image has a resolution of 7.4 km.
- The hazy appearance is due to dust in the atmosphere from a dust storm 3 weeks before the image was taken.



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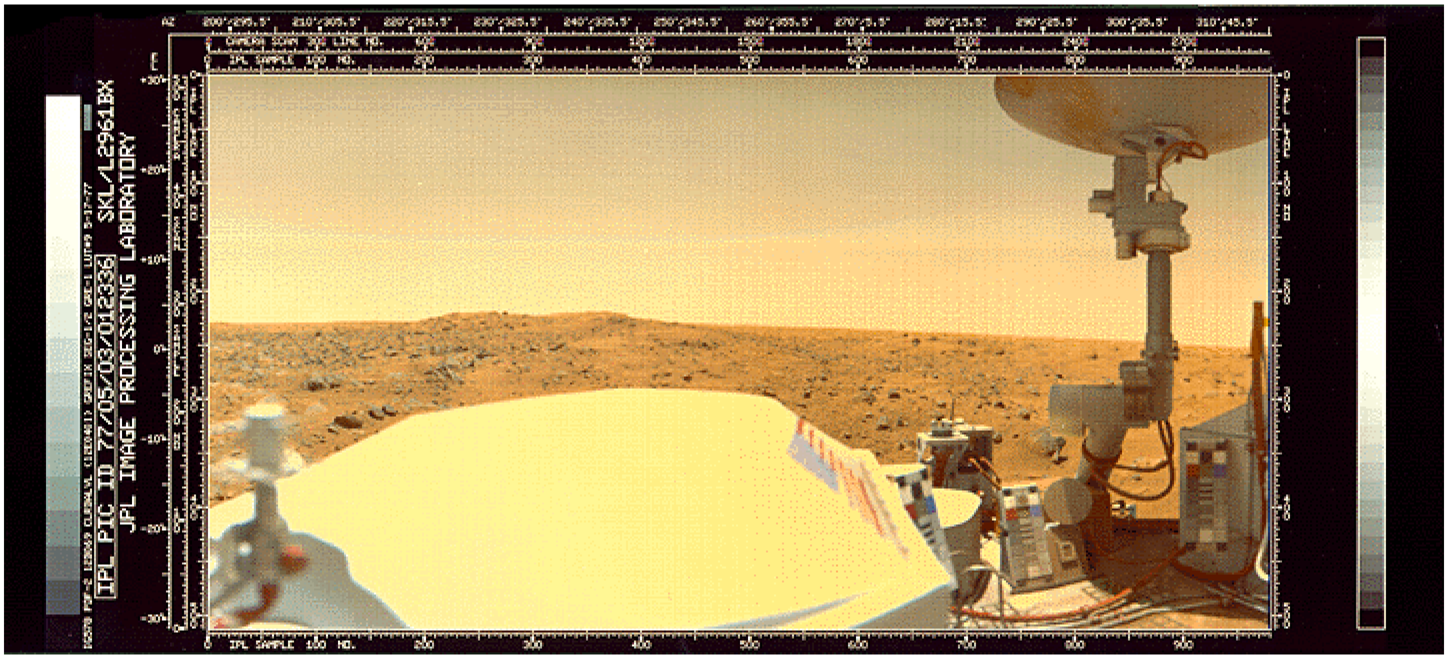
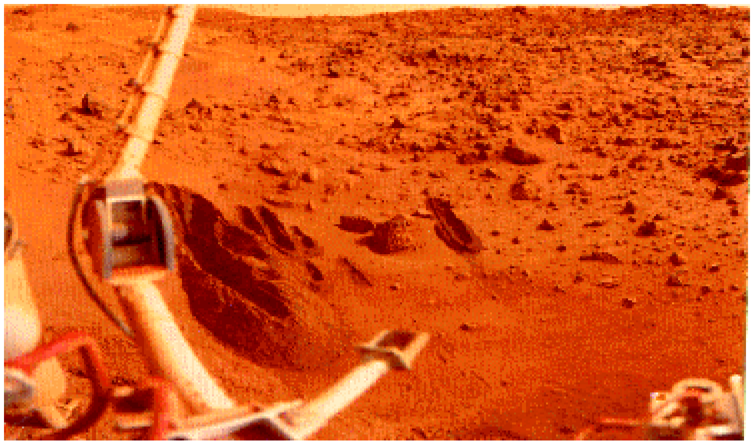
Viking Lander

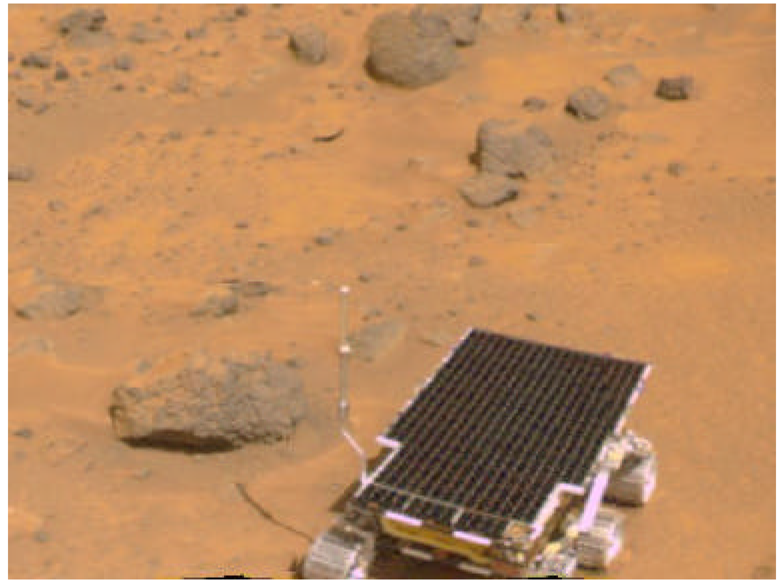


Viking 1 Lander image of Chryse Planitia, a wide, low plain covered with large rocks and loose sand and dust.

Mars from the Surface



The Viking 1 Lander sampling arm created a number of deep trenches as part of the surface composition and biology experiments on Mars.



Mars Pathfinder Mission Sojourner rover moving on the surface of Mars (1997)

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Moon from Apollo 10

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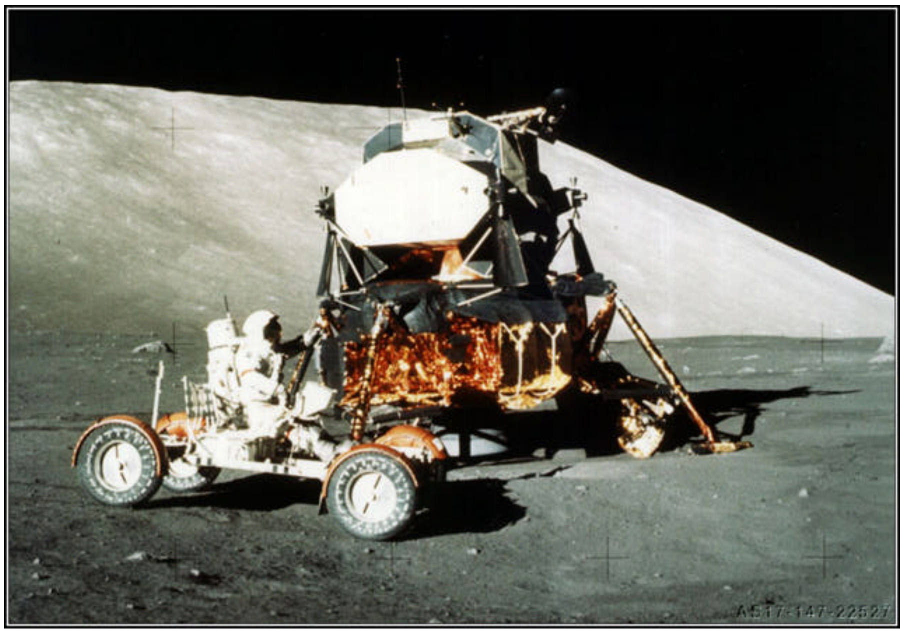
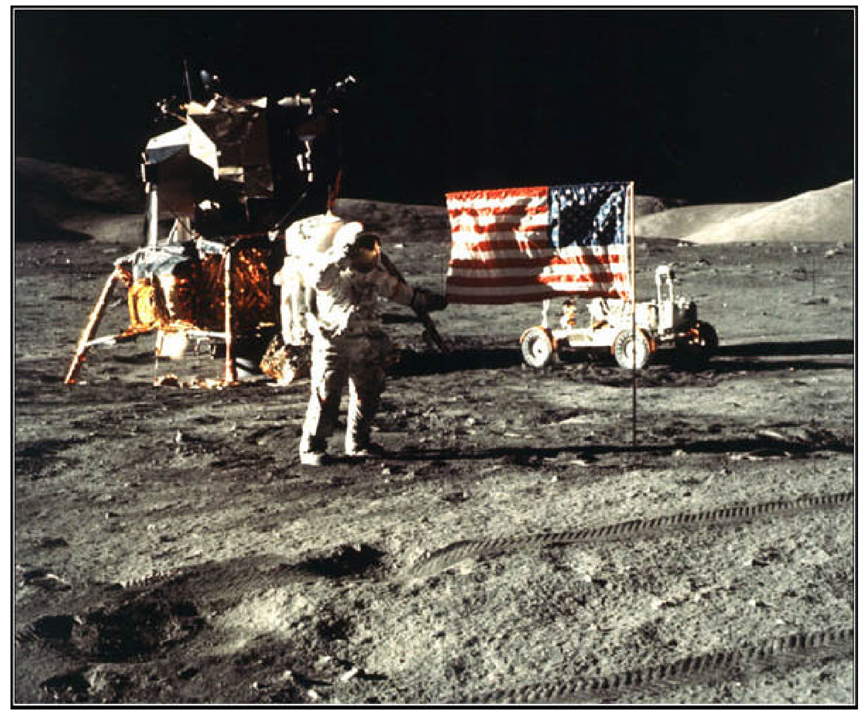
Earth Rise from Apollo 10

From the Lunar Surface





Apollo 17

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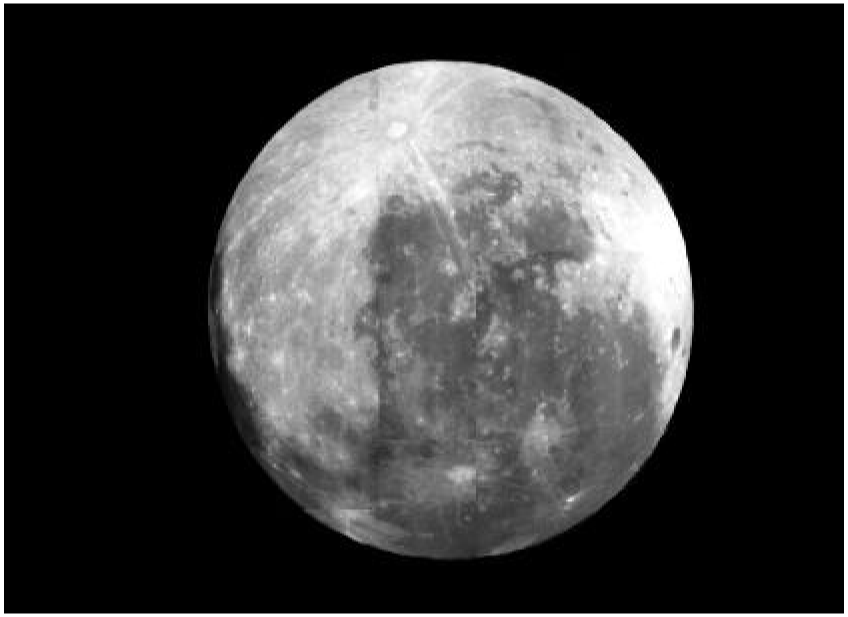
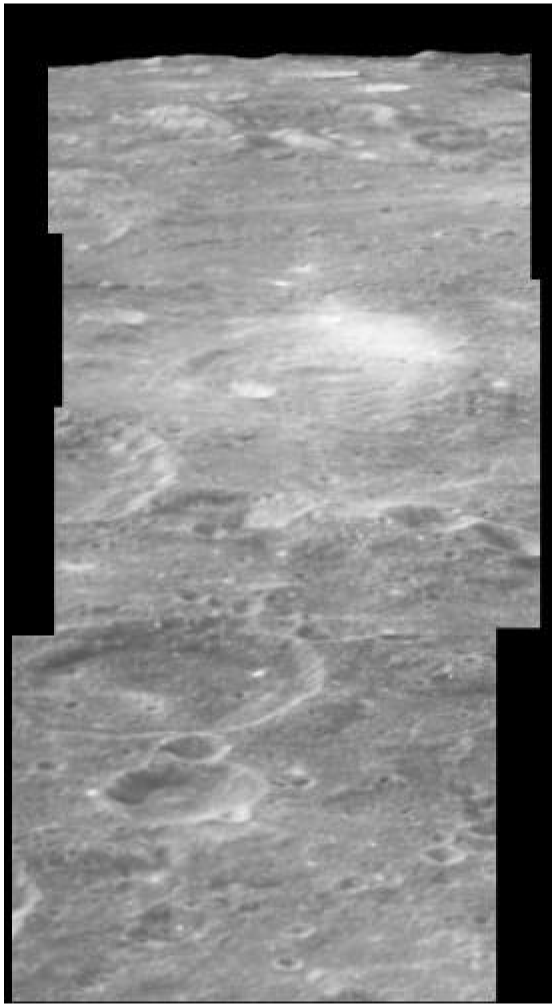
Clementine Mission, 1994



Moon lit by Earthshine



Apollo 16 Landing Site

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Mars Missions

Past

- NASA Mariner 3-4 (orbiter)
- NASA Mariner 8-9 (orbiter)
- Russia’s Mars 2-3 (orbiter)
- Russia’s Mars 5 (orbiter)
- Russia’s Mars 6 (capsule)
- NASA Viking 1-2 (landers)
- NASA Pathfinder (lander)

Present

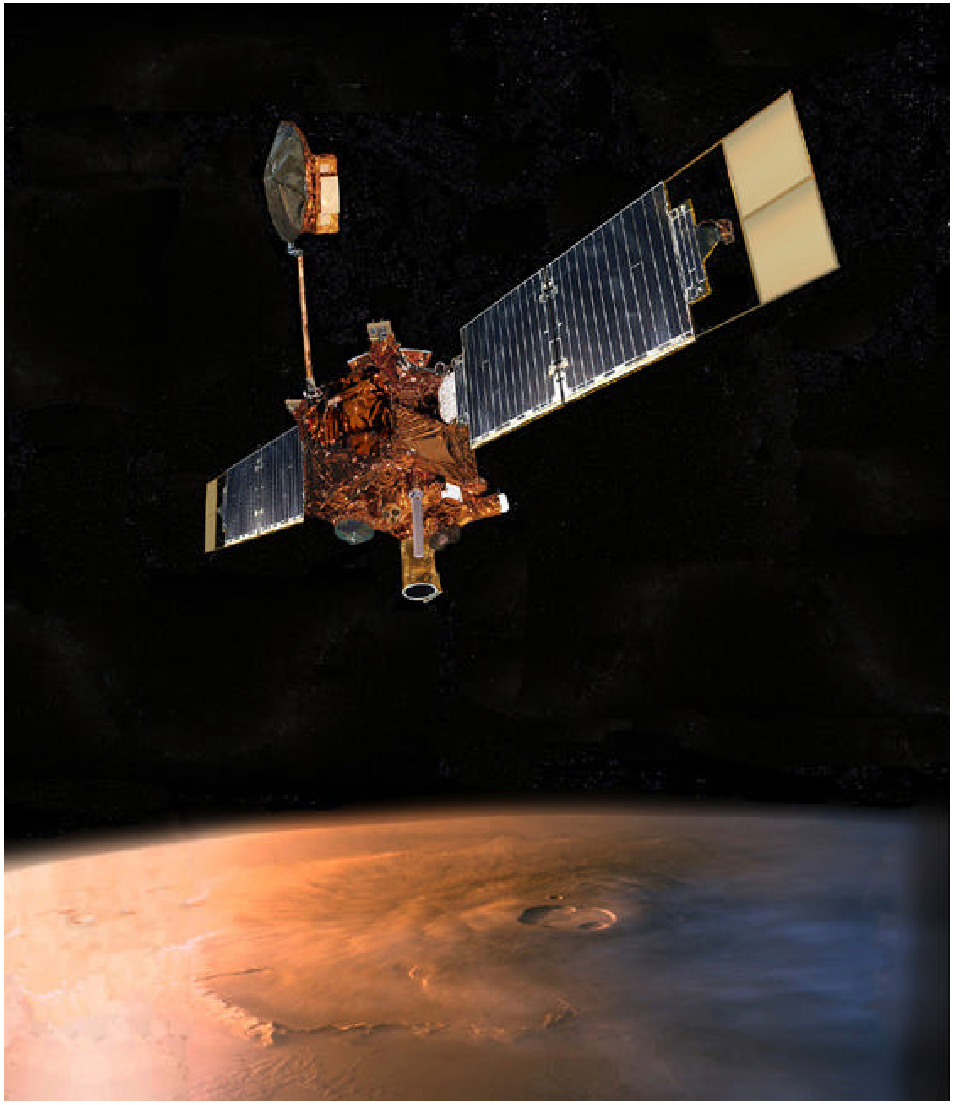
- NASA Mars Global Surveyor (orbiter)
- NASA 2001 Mars Odyssey (orbiter)
- ISAS 2004 Nozomi (orbiter)

Future

- ESA Mars Express
- NASA 2003 Mars Exploration Rovers
- NASA 2005 Mars Reconnaissance Orbiter
- NASA 2007 Smart Lander and Long-range Rover
- NASA Scout Missions
- NASA 2014-2016 Sample Return Missions

Mars Global Surveyor

- Launch: November 7, 1996
- Arrival: September 12, 1997
- Status: In orbit
- Mass: 767 kilograms (1,691 pounds)
- Science instruments: High-resolution Camera, Thermal Emission Spectrometer, Laser Altimeter; Magnetometer/Electron Reflectometer, Ultra-stable Oscillator, Radio Relay System



MSG Key Science Findings

- Pictures of gullies and debris flow features suggest there may be current sources of liquid water, similar to an aquifer, at or near the surface of the planet
- Magnetometer readings show that the planet's magnetic field is not globally generated in the planet's core, but is localized in particular areas of the crust
- New temperature data and closeup images of the Martian moon Phobos show its surface is composed of powdery material at least 1 meter thick, caused by millions of years of meteoroid impacts
- Data from the spacecraft's laser altimeter produced first 3-D views of Mars' north polar ice cap

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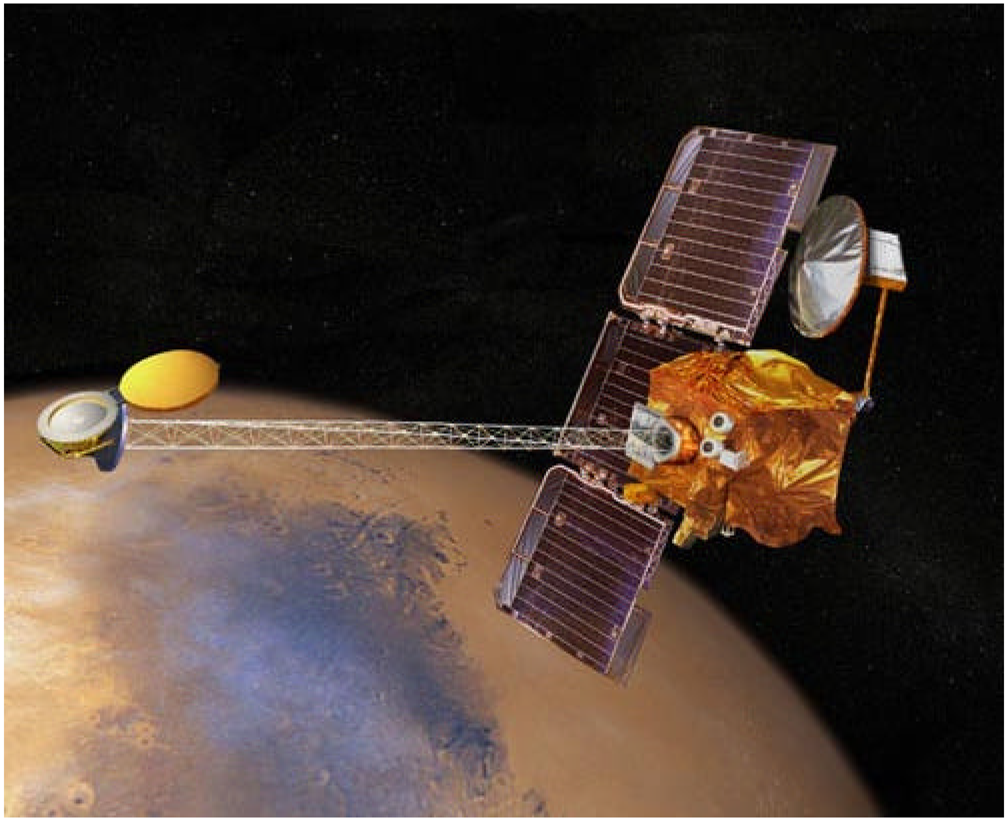
2001 Mars Odyssey

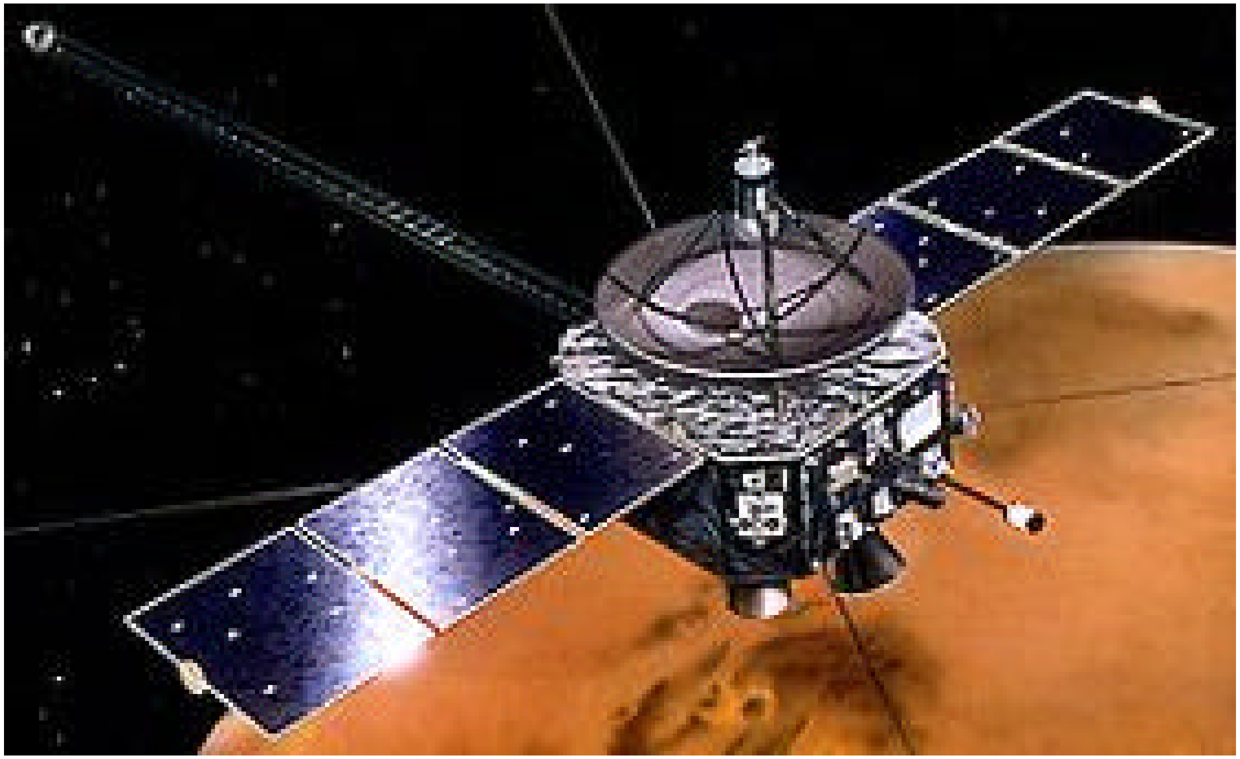
- Launch: April 7, 2001
- Arrival: October 23, 2001
- Mass: 758 kilograms, fueled
- Science instruments: Thermal Emission Imaging System (THEMIS), Gamma Ray Spectrometer (GRS), Mars Radiation Environment Experiment (MARIE)



Odyssey's Science Mission

- January, 2002 through July, 2004.
- Map amount and distribution of chemical elements and minerals that make up the Martian surface
- Will especially look for hydrogen, most likely in the form of water ice, in the shallow subsurface of Mars
- Will also record the radiation environment in low Mars orbit to determine the radiation-related risk to any future human explorers who may one day go to Mars

Nozomi



- The NOZOMI (PLANET-B): first Japanese Mars orbiter
- Launched on July 4,1998
- Scientific objective: study the Martian upper atmosphere with emphasis on its interaction with the solar wind.
- Status: now in heliocentric orbit, will arrive at Mars early in 2004.

Lunar Missions

Past

- **NASA:**
  - **Ranger 7-9 (1960s): Flyby**
  - **Surveyor 1,3,5-7: Landers**
  - **Lunar Orbiter 1-5: Orbiters**
  - **Apollo 8-10: Orbiters**
  - **Apollo 11-12, 14-17: Landers**
  - **Apollo 13: Flyby**
  - **Clementine (1994): Orbiter**
  - **Lunar Prospector (1998): Orbiter, Impactor**
- **Russia:**
  - **Luna 1-8: Flybys**
  - **Luna 9-12, 14,15,19,22: Orbiters**
  - **Luna 13,16,17,20,21,23,24: Landers**

Future

- **Japan:**
  - **SMART-1 (2002): Orbiter**
  - **Lunar-A (2003): Orbiter**
  - **Selene (2003): Lander**

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Physical Properties

	Mars	Moon
Orbit Inclinat.	23º 19’	6º 41’
Orbital Period	24 h 37 min	27.3 d
Diameter	6796 km	3476 km
Mass	0.64×10^{24} kg	7.35×10^{22} kg
Density	3.94 g/cm^3	3.36 g/cm^3
Surface gravity	0.379 g	0.167 g
Surface temp.	-140º to 20ºC	-170º to 130ºC

	Mars		Moon	
Surface pressure (mbar)	5 to 10		1 ? 10^{-12}	
Composition	**Gas**	**%**	**Gas**	**%**
	CO_2	95	Ar	79.2
	N_2	2.7	He	19.8
	Ar	1.6	O	1
	O_2	0.15	Na	Trace
	H_2O	0.03	H	Trace

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Martian Electrostatic Properties

- Most of what is known comes from earth-based measurements
  - Radar, radio occultation of spacecraft, microwave radiometry
  - Consistent with direct measurements of lunar rocks
  - Low conductivities

Martian Dust Storms

- Electrostatic charging of surface and airborne dust on Mars due to UV flux
- Contact charging due to wind-blown particles
- Planet wide dust storms observed with wind velocities up to 32 m/s
- Dust devils were observed with daily occurrence by Pathfinder

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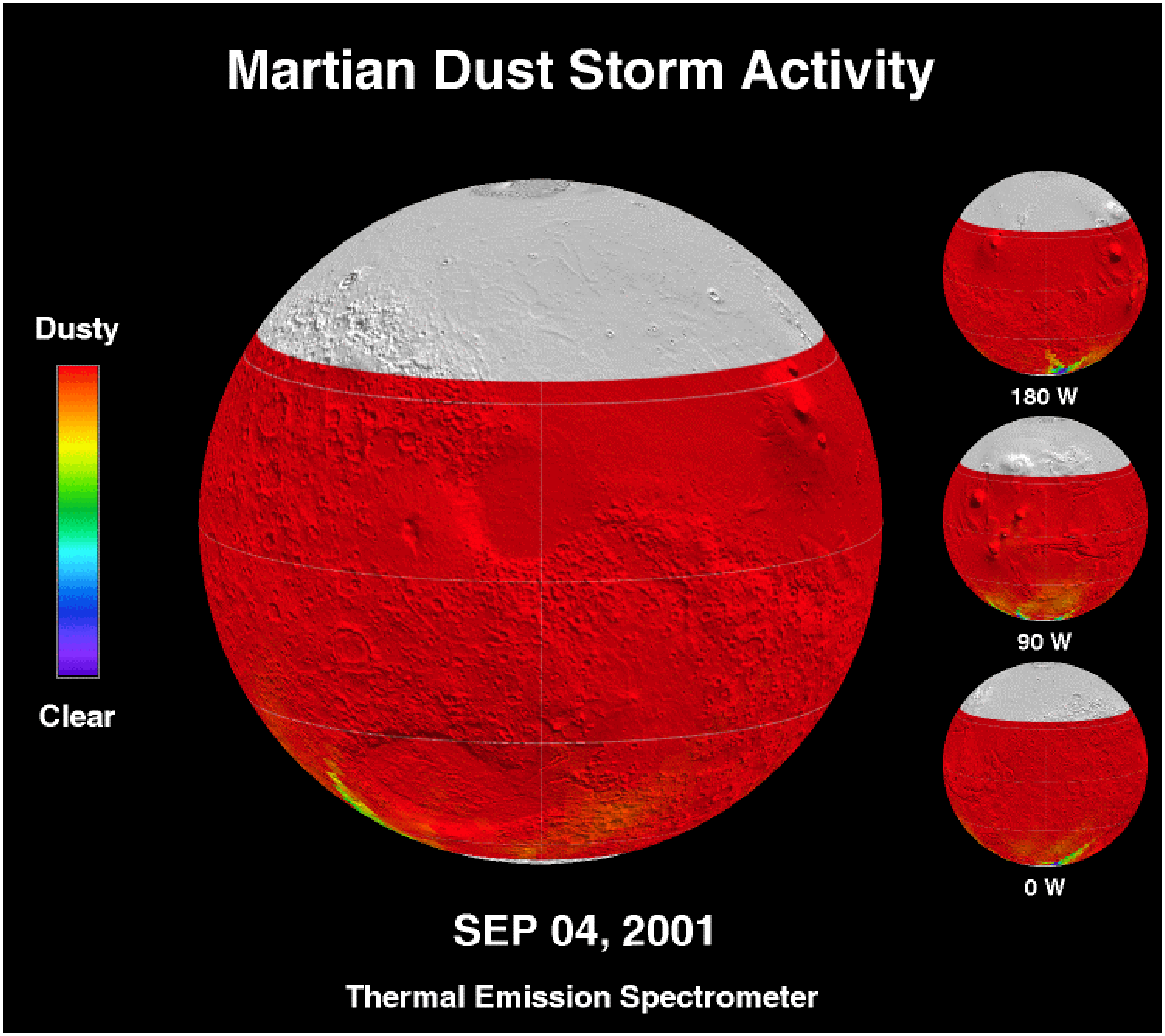

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Martian Dust Devils

- Dust devils have been observed by the Mars Global Surveyor's Orbiter Camera (MOC) to be <u>2 km in diameter</u>, and <u>8 km in altitude</u>.

MGS/MOC May 13, 1999

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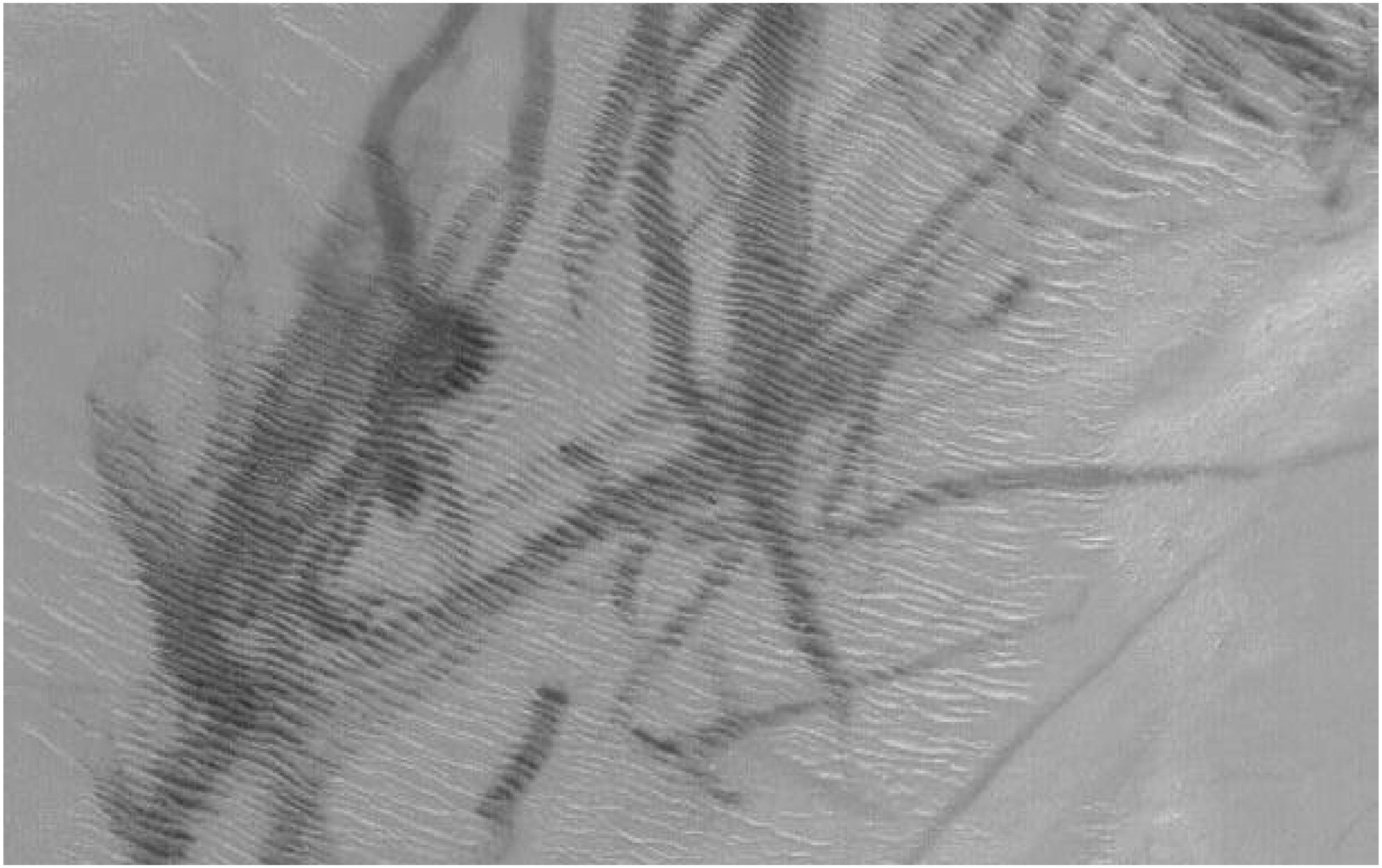
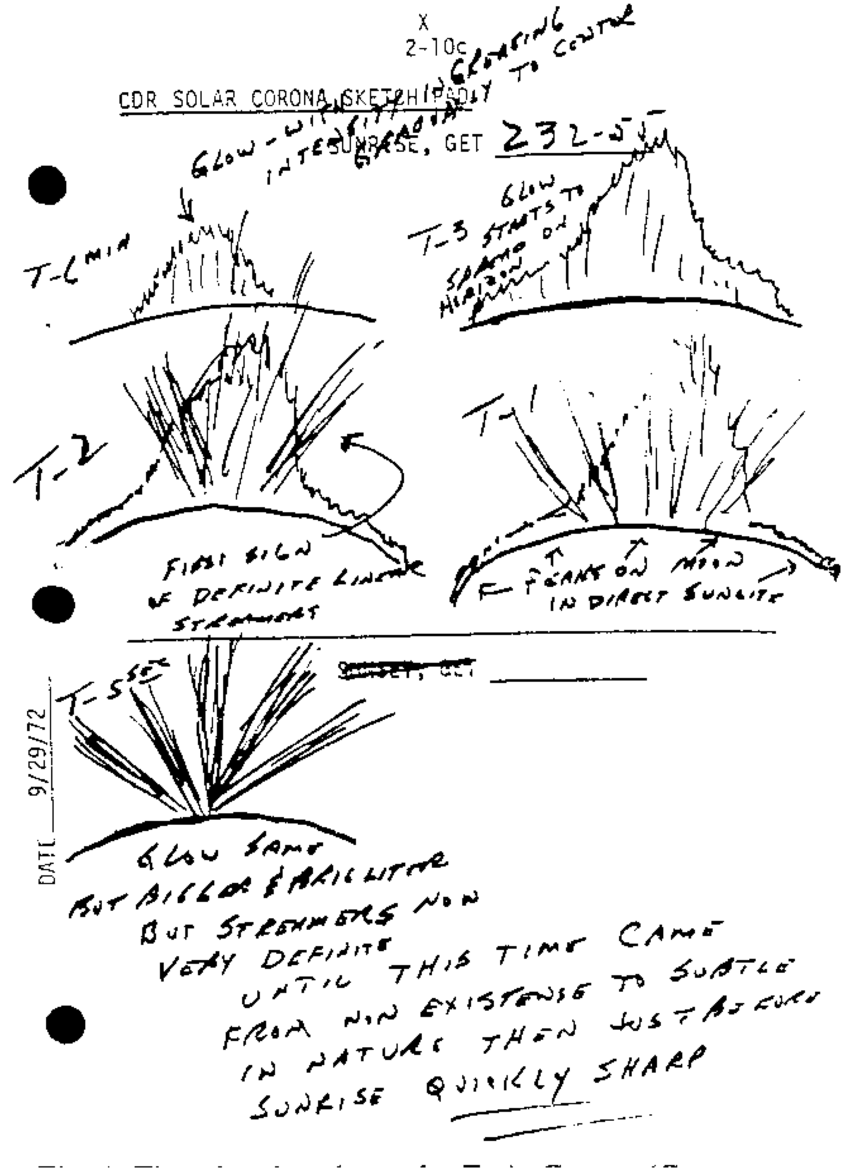
Martian Dust Devils

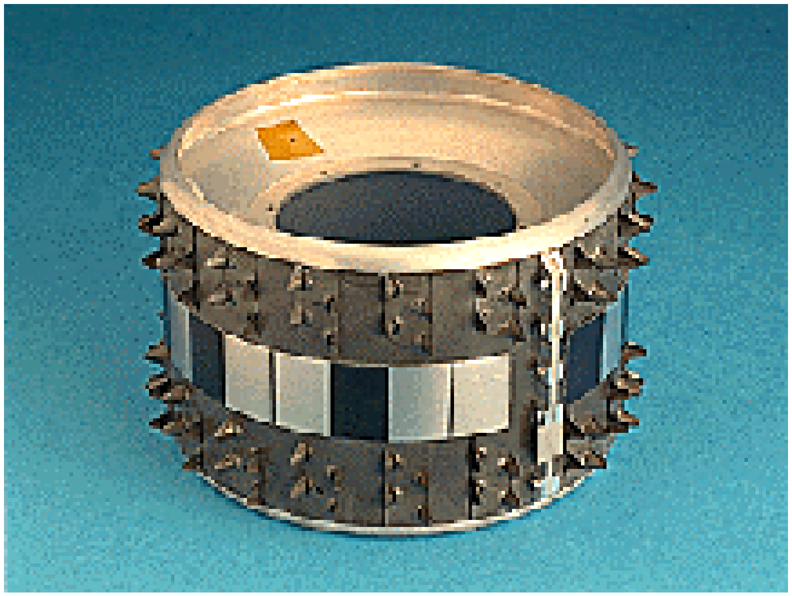


Horizon Glow on the Moon

- Apollo astronaut sketches from orbit
- Lunar Surveyor spacecraft observations and Lunar Ejecta and Meteorites (LEAM) Experiment on Apollo 17: dust clouds
- Evidence for dust transport?
- Electrostatic charging of dust due to solar wind particles and to UV



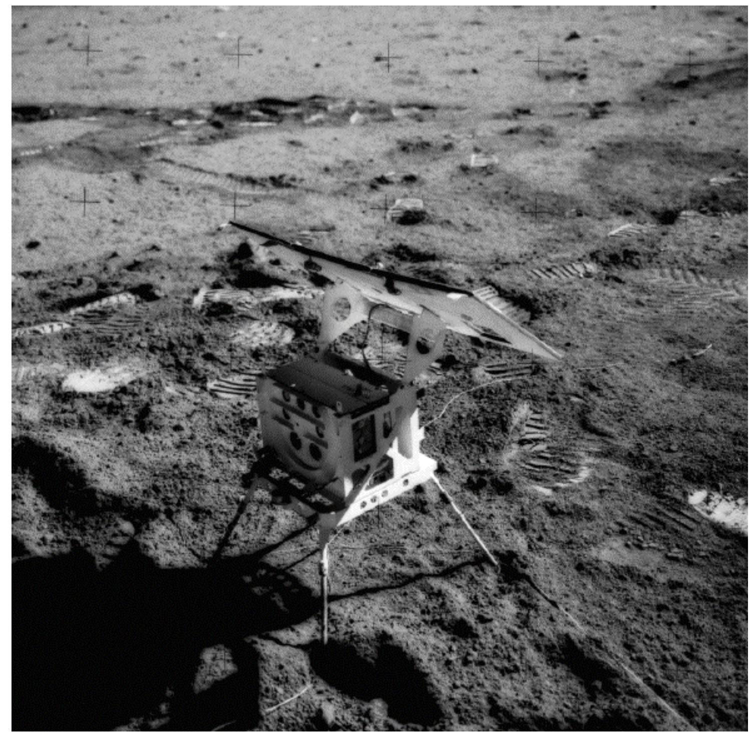
Martian *In situ* Experiment



- Wheel Abrasion Experiment (WAE) on Pathfinder used thin films of Al, Ni, and Pt, (200A - 1000A), deposited on black, anodized Al strips attached to the rover wheel.
- As the wheel moved across the martian surface, a photovoltaic sensor was used to monitor changes in film reflectivity.
- Dust accumulation due to contact and frictional charging

Lunar *In Situ* Experiment

- Surface Electrical Properties (SEP) experiment on Apollo 17
- Measure transmission, absorption, and reflection of electromagnetic radiation of lunar surface



$?_r$ = 3 to 4 at 1 to 32 MHz on surface

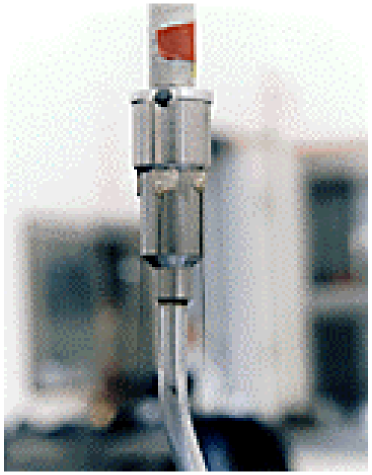
$?_r$ = 6 to 7 at 1 to 32 MHz, 50 m below surface

Ground Experiments

- 1973 lab experiments in Martian-like atmosphere:
  - Dust particle q ? 10^4 e^-
- In dusty, turbulent Martian environment:
  - E ? 5 kV/m

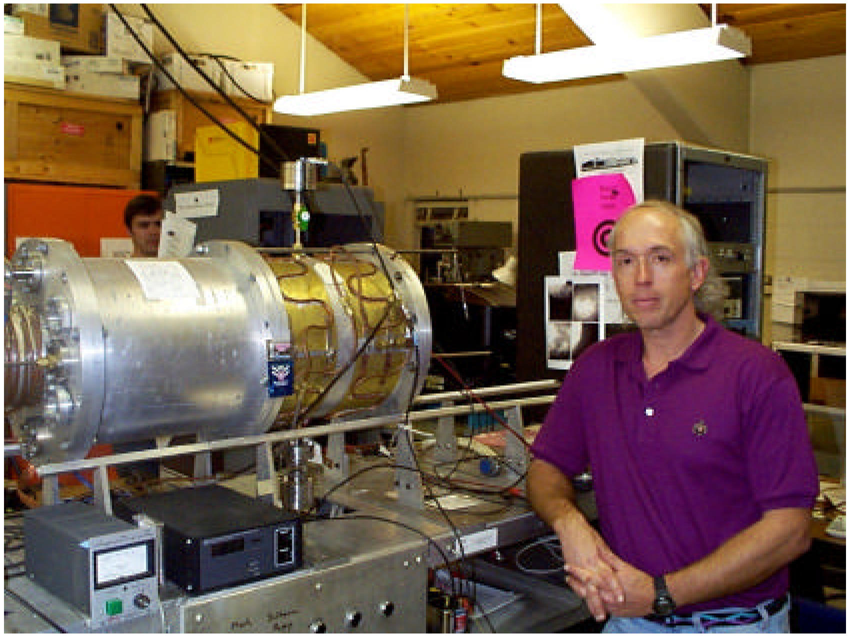
Pathfinder Rover

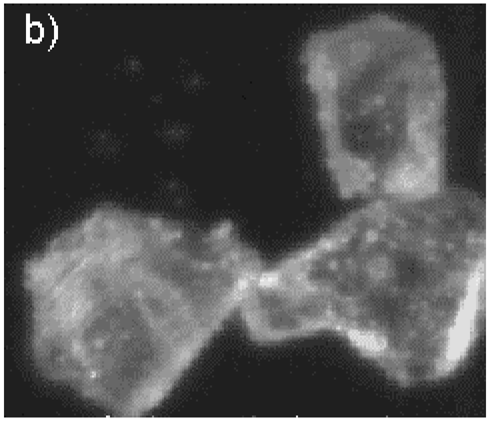
- Model of Sojourner wheel
- SME and simulant
- Potentials ? 100 V
- Av arc times of 1?s
- *I* ? 10 mA
- Discharge points to Sojuourner antenna base



Lunar Dust Charging Experiment

- Simulated lunar dust dropped into plasma
- Measured the charge on the particles.
- Repeated measurements on soil samples from the Apollo 17 landing site





Martian Simulant

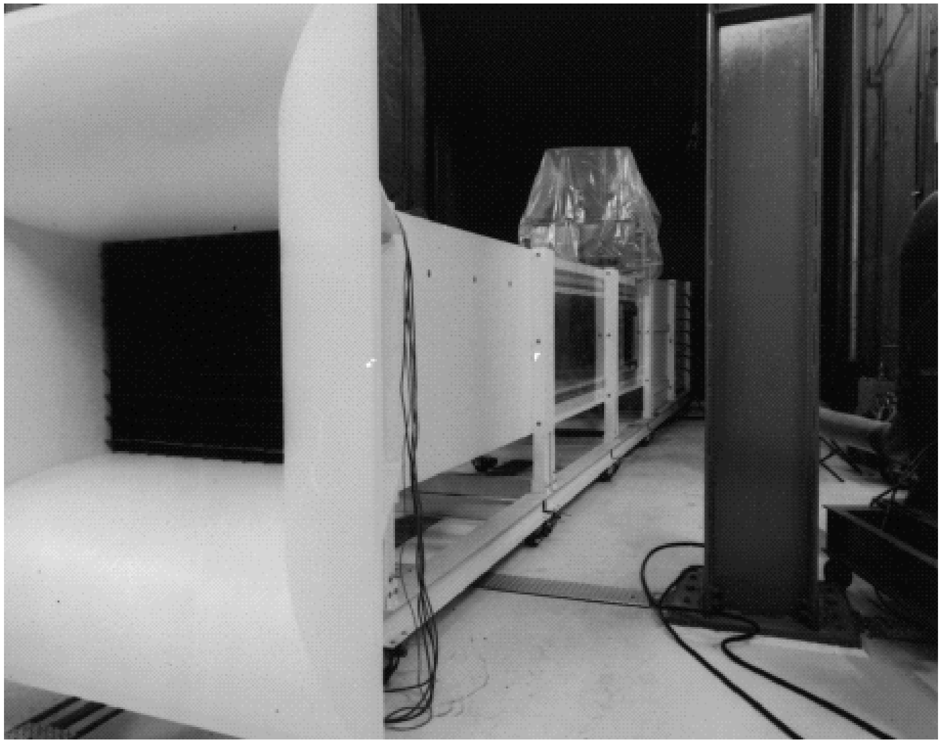
- Simulant: is the 1 mm and smaller fraction of altered volcanic ash from Hawaiian cinder cone
- Approximates Viking, Pathfinder measurements
  - reflectance spectrum
  - mineralogy
  - chemical composition
  - grain size
  - density
  - porosity
  - magnetic properties

Table 1. JSC Mars-1 Chemical Composition (Wt%)

Oxide	Viking 1	Pathfinder	JSC Mars-1	
			Fine	Coarse
SiO_2	43	44.0	40.2	39.3
Al_2O_3	7.3	7.5	25.1	26.2
TiO_2	0.66	1.1	3.53	3.42
Fe_2O_3	18.5	16.5	12.4	15.6
MnO	NA	NA	0.65	0.49
CaO	5.9	5.6	4.08	3.51
MgO	6	7.0	1.14	0.97
K_2O	<0.15	0.3	NA	NA
Na_2O	NA	2.1	1.79	0.91
P_2O_5	NA	NA	1.13	1.91
SO_3	6.6	4.9	0.86	0.29
Cl	0.7	0.5	NA	NA
LOI*	NA	NA	21.8	

*LOI: Loss on ignition. Weight loss after 2 hrs at 900°C; includes H_2O and SO_2

Environmental Simulators



- MARSWIT: 13 m wind tunnel
- 3 mb to 1 bar
- Wind velocities up to 150 m/s at 3 mb

Mars Environmental Chamber

- Volume of 1.5 m^3
- Completely automated
- SME:

  10 mb

  CO_2

  -90ºC

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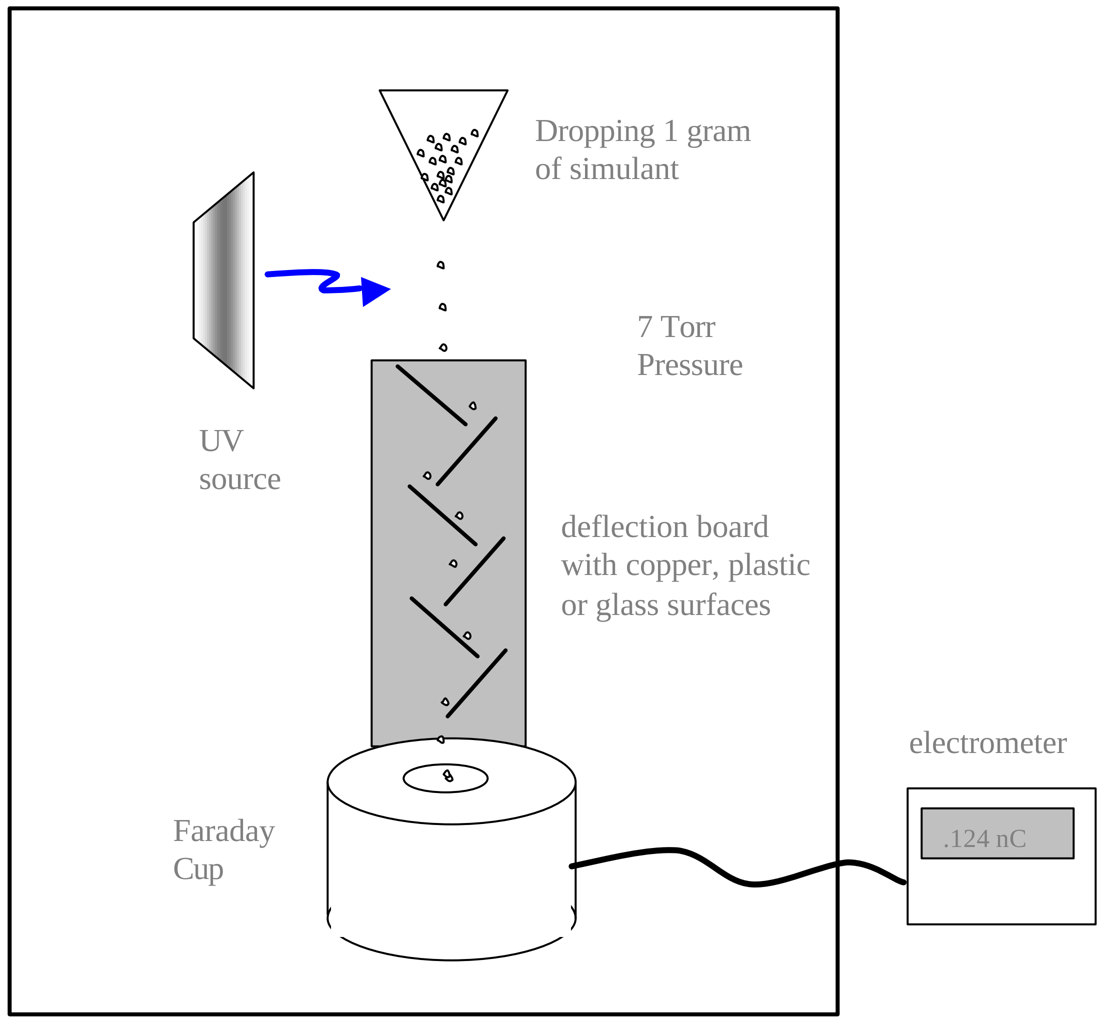
Deflection Board Experiment

- 1 g of Martian simulant soil (5 to 300 ?m) at 10 mb
- Faraday cup collected particles



Deflection Board Experiment

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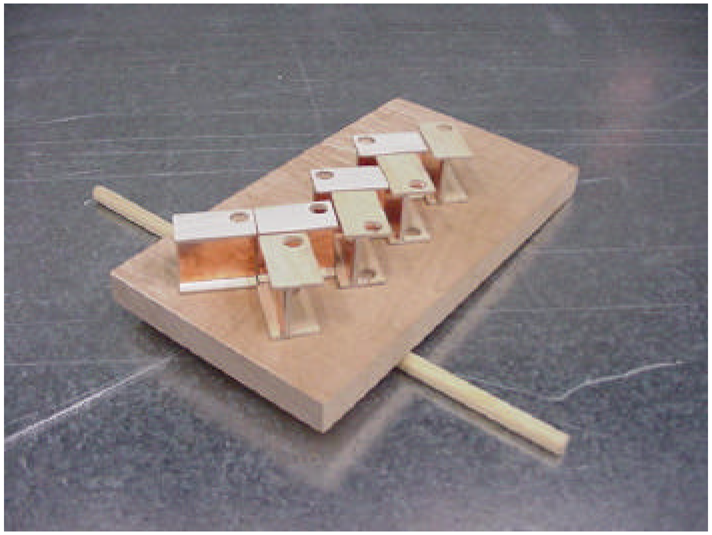

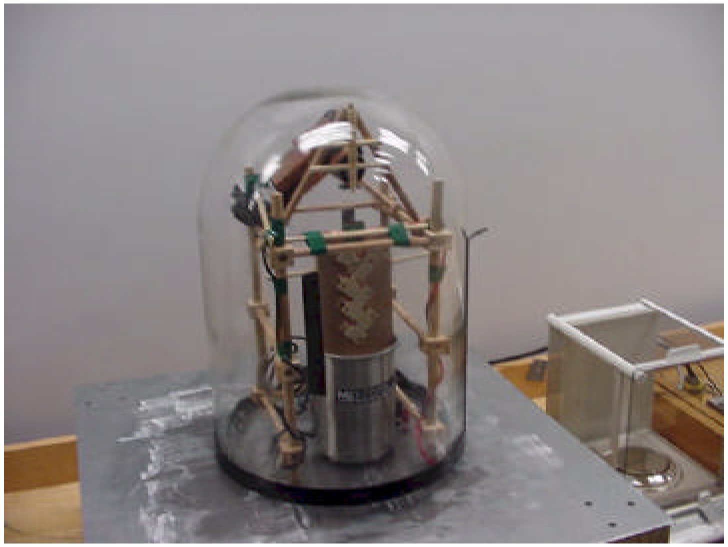

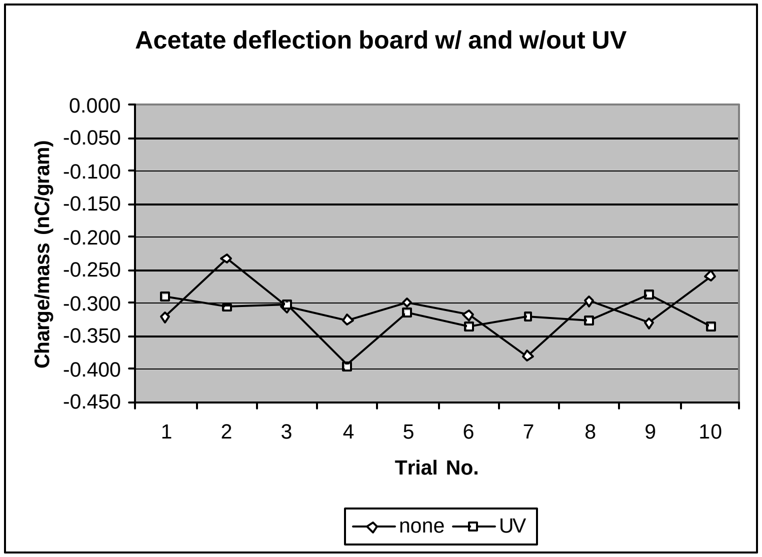

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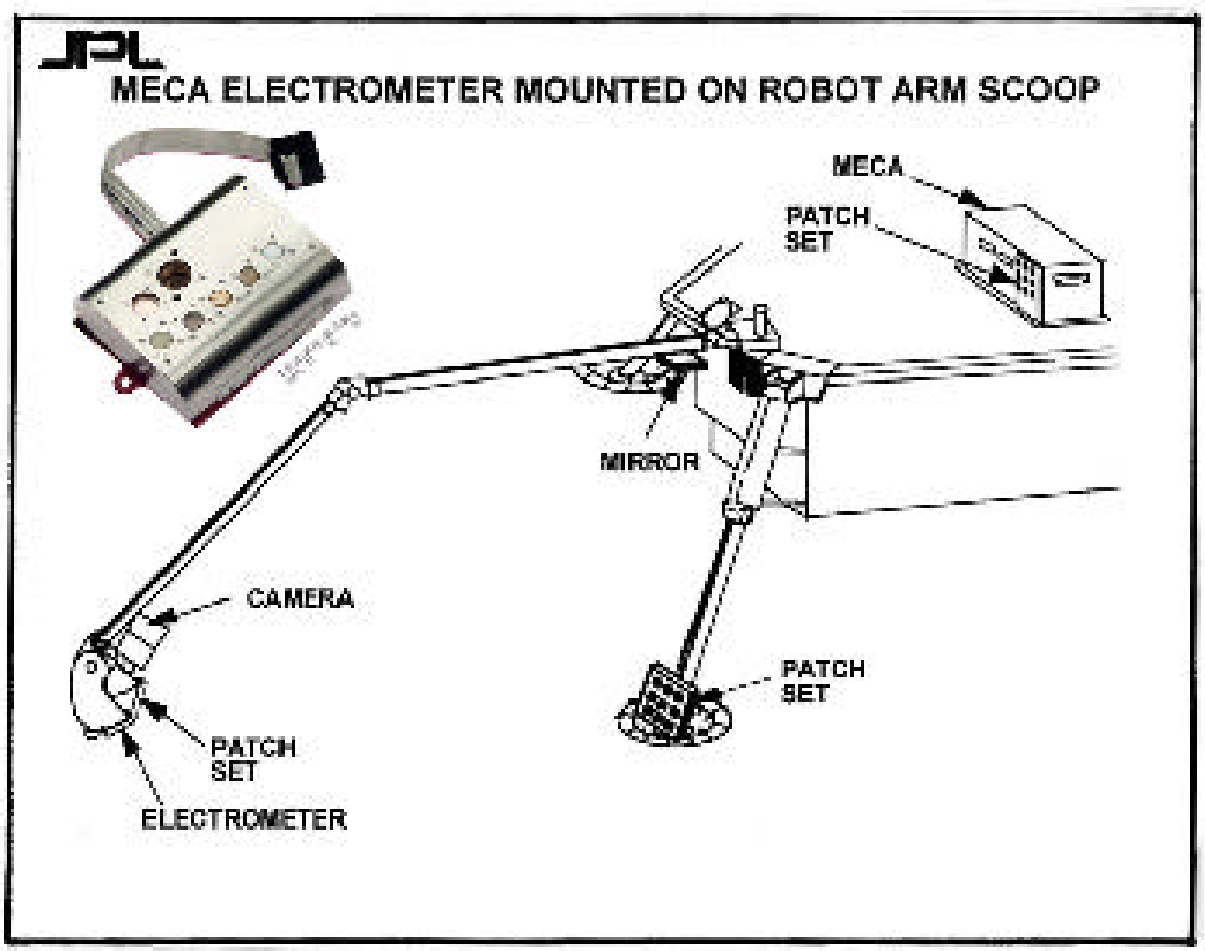
Flight Instrument



Five Insulators

- –Fiberglass/epoxy G-10
- –Lexan?
- –Teflon
- –Rulon J?
- –Lucite

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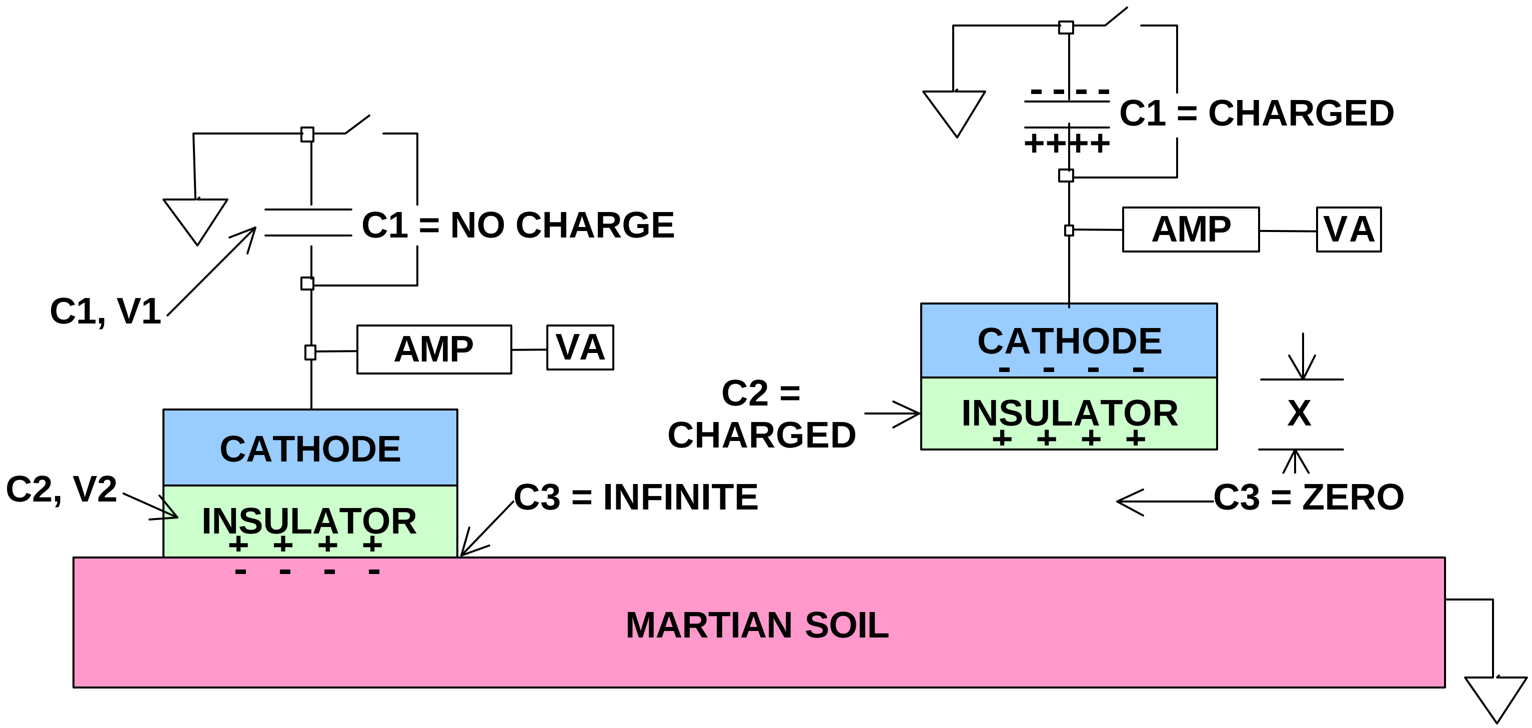
Basic Electrometer Design



Mission Environment

Location	**Parameter**	**Value**
Earth	Planetary Protect. (H_2O_2)	55°C
Launch	Launch Acceleration	3000 g
Cruise	Radiation Dose	1500 rad/yr
Mars	Radiation Dose	10 rad/yr
Mars	Temp Operate	-40 to 30°C
Mars	Temp Survival	-107 to 20°C
Mars	Temp Variation	60°C/day
Mars	Pressure	5-10 mb [2]
Mars	Atmosphere	CO_2 95%
Mars	Humidity	<0.1 % [2]

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MECA Electrometer Performance

Parameter		
Tribo Voltage Sensitivity	1.8 kV/V	0.25 nC/V
Tribo Voltage Range	±7.2 kV	±1 nC
Tribo Voltage Resolution	3.5 V	0.5 pC
Ion Curent Sensitivity	30 pA/V	
Ion Current Range	±120 pA	
Ion Current Resolution	60 fA	

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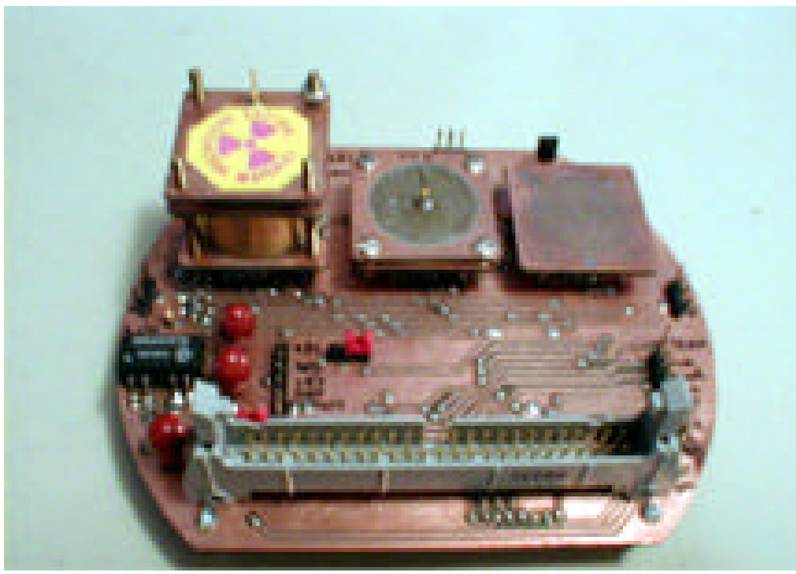
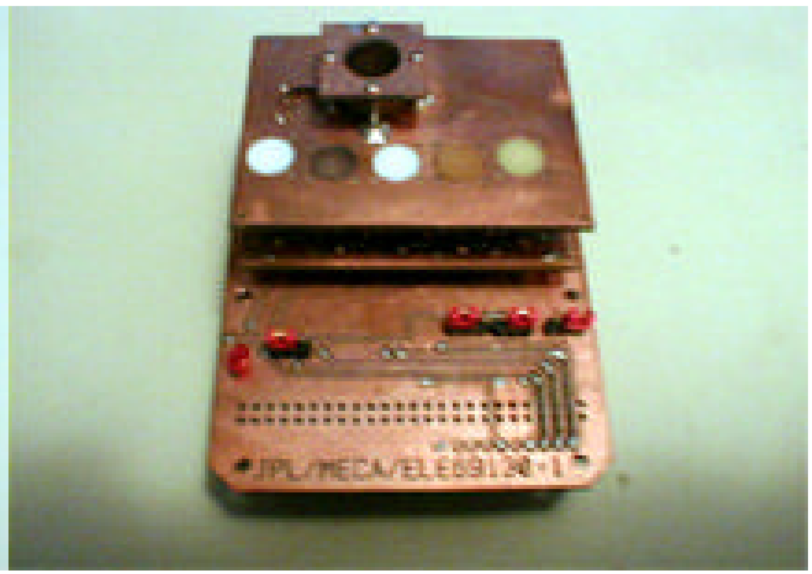
Prototypes





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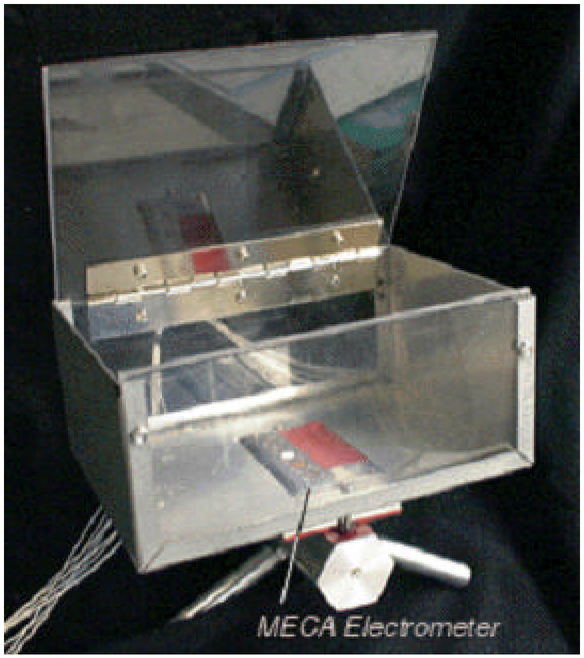
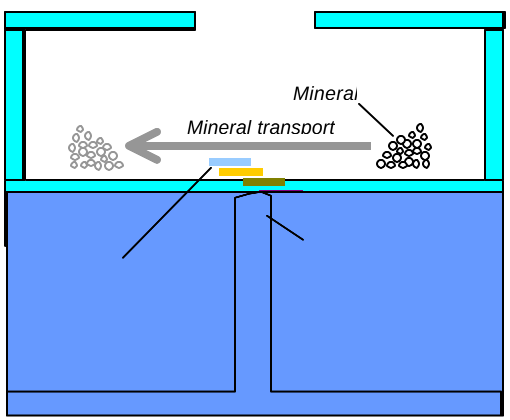
Flight Version

No.	Material Name	Dielec. Constant 1 MHz	Bulk Resistivity (ohm-cm)
TRI1	G10, FR4	4.7	7.8E15
TRI2	Lexan?	2.96	2E16
TRI3	Teflon? , PTFE	2.1	1E18
TRI4	Rulon J?	2.4	8.2E18
TRI5	Lucite? , PMMA	2.63	>5E16 >1E14

Rock & Roll Experiment





- Multisensor electrometer at bottom of chamber
- Simulant particles roll back and forth
- Experiments were done at partial Martian simulated conditions:
  - 10 mbar atmospheric pressure
  - CO_2 atmosphere

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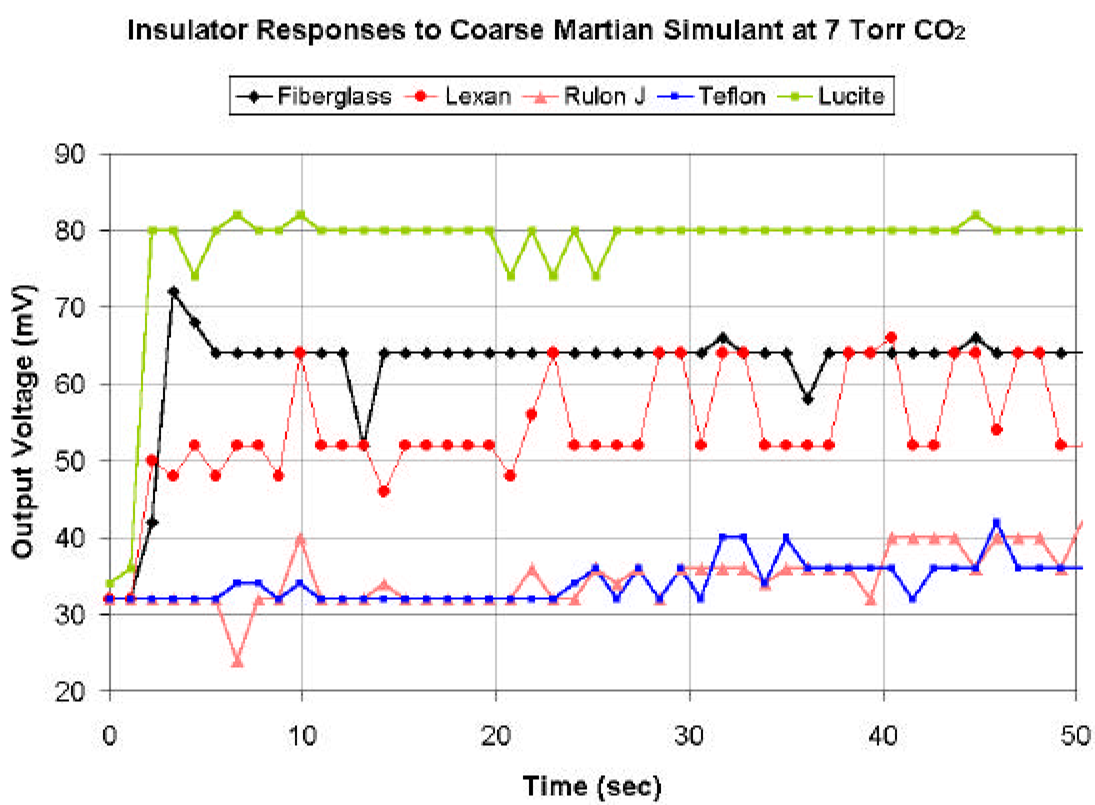
Rock & Roll Results

- Initial contact at 2 s
- Lucite 20 pC
- Fiberglass 16 pC
- Lexan 13 pC

- Short, rapid decay

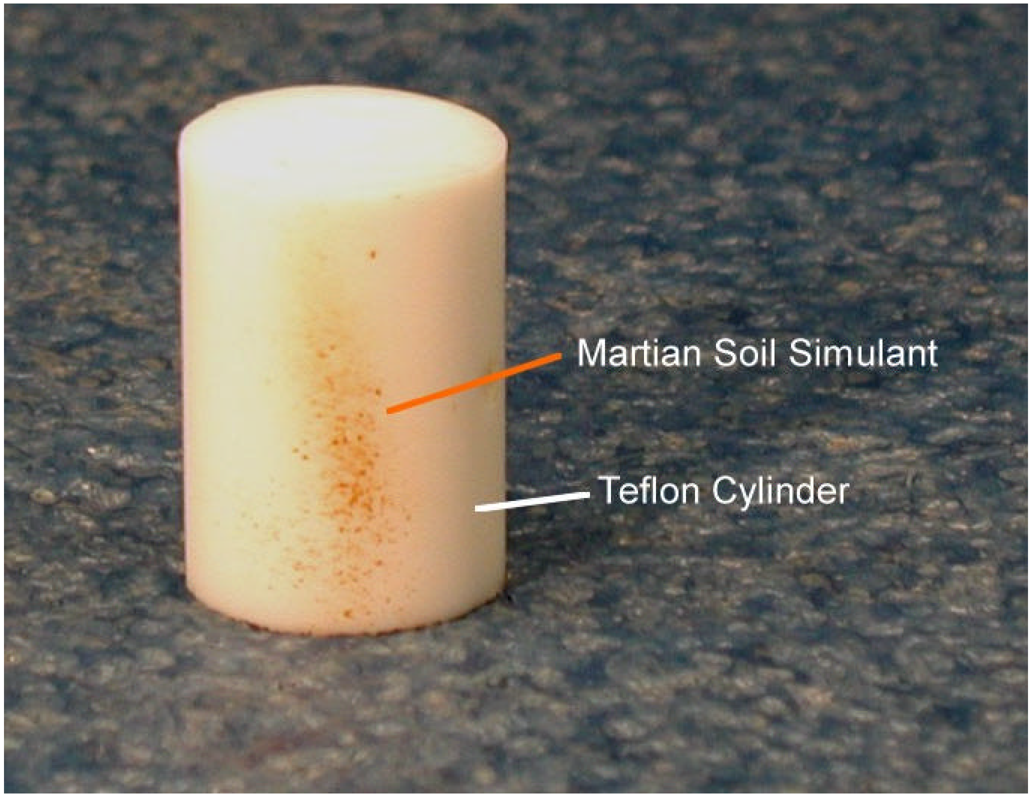
- Note: Voltage offset was 32 mV



Charging of the five insulators in the MECA electrometer with the Mars Simulant. Results are typical of many runs at 10-130 mb.

Wind Simulation Experiments

- Propel 5 to 20 ?m particles at samples under SME
- Q ? -5 to + 19 pC



Modeling

Navier-Stokes: The basic equation used to study fluid flow is the Navier-Stokes force density relation. With electrostatic body forces the general equation is

$$? \frac{d\vec{v}}{dt} ? ?? P ??? {}^{2}\vec{v} ? \tfrac{1}{3} ? ? ? ? \vec{v} ? ? \vec{g} ? \tfrac{1}{2} ? ? ?_{p} ? 1 ? ? ?_{g} ? E^{2}$$

Where

P ?	Ambient Pressure
? ?	Kinematic Viscosity
$\vec{v}$?	Wind Velocity Vector
? ?	Gas Density
? ?	Gas/Dust Fraction
$?_{p}, ?_{g}$?	Electric Constant, Dust, Gas respectively

Modeling

With the flow parameters being 7 Torr CO_2 and 30 m/s, incompressible conditions apply and the third term can be dropped due to the continuity equation. Gravity forces are negligible, so the fourth term representing the gravity body force can be dropped as well.

$$? \frac{d\vec{v}}{dt} ? ??\, P ???\, {}^{2}\vec{v} ? \tfrac{1}{2} ??_{p} ? ?1 ? ? ??_{g} ? ? E^{2}$$

- The Navier-Stokes equation can only be solved numerically.
- Preliminary simulations of gas flow at Earth and Martian atmospheric conditions have been performed and are shown in the following graphs.

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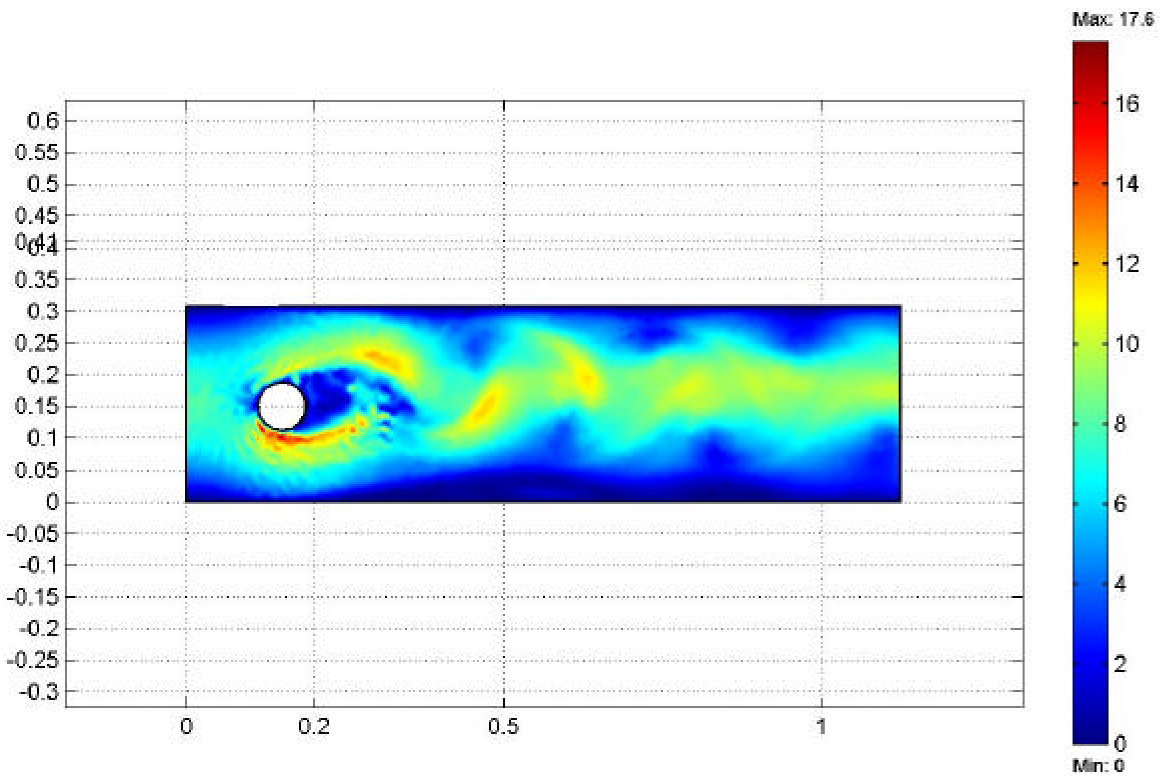
Modeling



Flow Past a Cylinder – Low Re Mars Conditions

Conclusions

- Most of what we know about electrostatics on Mars and the Moon: from ground based experiments
- No experiment has been flown designed solely for electrostatics
- Work continues in different labs for future flight experiments

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Acknowledgements

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